A MANUAL

OF

MARINE ENGINEERING:

COMPRISING

THE DESIGNING, CONSTRUCTION, AND WORKING OF MARINE MACHINERY.

BY

A. E. SEATON,

LECTURER ON MARINE ENGINEERING TO THE ROYAL NAVAL COLLEGE, GREENWICH,
MEMBER OF THE INSTITUTION OF NAVAL ARCHITECTS, MEMBER OF
THE INSTITUTION OF MECHANICAL ENGINEERS, ETC.

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collision, and capability of handling the ship from on deck without stopping the engines; but in actual practice, from the causes indicated above, the efficiency is very low, and the cost and room occupied very large.

Hydro-motor.—In this plan there is no real engine or propeller; the water is simply ejected from two cylindrical chambers alternately by the direct pressure of the steam on its surface. When the one chamber is emptied, steam is shut off from the boiler, and allowed to escape to a condenser; the water flows quickly into the vacuous chamber, and, when it fills, its communication is closed to the condenser and opened to the boiler. A ship has been fitted out on this plan, and proved fairly successful, for the condensation of steam on the walls of the wet chamber is very slight, owing to the short time of exposure, and that on the surface of the water equally small, for there is no convection to carry away the heat into the body of the water. The steam was also worked expansively, and the inventor claims for it quite as high an efficiency, judged by coal consumption, as that of a good compound screw engine. The walls of the chambers are lined with wood, so that there may be as little loss as possible by conduction.

However much the loss from such causes, as stated, may be set off by the gain from absence of mechanism (and it is possible that the saving may even outbalance the loss), there still remains the same objection which militates so strongly against jet propulsion—viz., the large pipes, valves, and passages.

The plans for ejecting a stream of water by means of pistons, floats, &c., are very numerous, and since most of them have been re-invented many times over, the patents are legion. None of them have, however, been proved to be equal in efficiency to the commonest of screws, and many of them are most egregious mistakes from want of knowledge of first principles.

Common Paddle-Wheel, or Wheel with Radial Floats.—This, the simplest and oldest form of paddle-wheel, consists essentially of a wrought-iron frame wheel, having two or more sets of arms fitted to a cast-iron "hub" or "boss," and connected by rims and cross-stays so as to have the necessary rigidity and interdependence of the several parts. Flat boards are secured in a radial direction to the arms by hook bolts, so that when the wheel is turned around, the floats, as these boards are called, drive a stream of water through the still water in the opposite direction to that which the ship takes. If the water were unyielding, the action of the wheel would be analogous to that of a pinion on a rack in the mangle motion, so that the motion onward of the ship per revolution would be $3{\cdot}1416 \times$ the diameter of the *pitch circle* of the floats or circle of centres of pressure. But as the water yields to the pressure of the float, the action is the reverse of that of an undershot radial water-wheel; the float drives a stream of water equal in area of section to its own area, and with a velocity $(V - v)$, as before.

Let D be the effective diameter of the wheel, A the area of a pair of floats (one on each wheel acting at once) in square feet. R the revolutions of the wheel per second, and v the speed of the ship in feet per second.

Weight of a cubic foot of sea-water = 64 lbs.

The velocity of the floats per second $V = \pi \times D \times R$.

The quantity of water operated on in a second $= A\ (\pi \times D \times R)$ cubic feet, or $64\ (A \times V)$ pounds.

The velocity imparted to the water is $(V - v)$.

Taking gravity as 32,

$$\text{Momentum of water} = \frac{64\ (A \times V)}{32} \times (V - v)$$
$$= 2\ (A \times V) \times (V - v).$$

which is, as before explained, equal to the resistance of the ship and the force on the floats, and consequently the *thrust* of the shaft on the bearings on the side of the ship.

But this is only strictly true when the float is just immersed and vertical, as there are other actions which seriously interfere with the efficiency of the radial paddle-wheel.

The floats of a radial paddle-wheel of necessity enter the water obliquely under all circumstances, and when the ship is deeply laden, so that the wheel is deeply immersed, the obliquity is very great. The disturbance consequent on this is such as to raise a stream of water nearly parallel to the float, which is finally projected past the emerging floats and astern of the wheel, and appears to come from them, and so giving rise to the generally received opinion, that the cascade of water usually observed in wake of a radial wheel, is that carried up by the floats in leaving the water. Again, the floats do raise a certain amount of water by their obliquity to the surface of the water, and thereby divert very considerably the "race" set up by the float when vertical.

On this account, it is impossible to estimate with any degree of accuracy the actual momentum of the race of water from a radial wheel. Paddle-wheels with radial floats are now but seldom employed, and only in tugs where prime cost is a paramount consideration, or in small river steamers having comparatively large diameters of wheel with a small amount of dip, or for service in barbarous countries, where simplicity and a minimum risk of derangement is a necessity.

The *effective diameter* of a radial wheel is usually taken from the centres of opposite floats; but it is very difficult to say what is absolutely that diameter, as much depends on the form of float, the amount of dip, and the waves set in motion by the wheel. The slip of a radial wheel is from 15 to 30 per cent., depending on the size of float.

The area of one float may be found by the following rule :—

$$\text{Area of one float} = \frac{\text{I.H.P.}}{\text{D}} \times \text{C}.$$

D is the effective diameter in feet, and C is a multiplier, varying from 0·25 in tugs, to 0·175 in fast-running light steamers.

The breadth of the float is usually about $\frac{1}{4}$ its length, and its thickness about $\frac{1}{8}$ its breadth. The number of floats varies directly with the diameter, and there should be one float for every foot of diameter.

Example.—To find the particulars of the floats for a radial wheel 16 feet effective diameter, the I.H.P. of the engines being 400.

$$\text{Area of one float} = \frac{400}{16} \times 0{\cdot}25 = 6{\cdot}25 \text{ square feet.}$$

$$\text{Length} \times \frac{\text{Length}}{4} = 6{\cdot}25.$$

$$\text{or Length} = \sqrt{4 \times 6{\cdot}25} = 5 \text{ feet.}$$

$$\text{Breadth} = \frac{5}{4} = 1{\cdot}25 \text{ feet, or 15 inches.}$$

$$\text{Thickness} = \frac{15}{8}, \text{ or } 1\tfrac{7}{8} \text{ inches.}$$

Number of floats, 16.

The floats are usually made of elm, although any tough strong wood which withstands the action of water will do equally well. They are commonly rectangular in form, with the corners rounded off and the dipping edges bevelled at the back, so as to enter the water as easily as possible.

To avoid the shock of entry, the floats are sometimes shaped so that the middle of the float enters first, the sides being cut away taper for that purpose. To avoid the oblique action of the float on entry, the arms are sometimes bent so that the float is perpendicular before arriving at the point immediately below the centre of the wheel; it is consequently more oblique on emerging than that of the common wheel, and tends to increase the lifting of the water then.

The wheel is also sometimes made with the floats inclined to the axis, so as to throw a stream of water away from the hull of the ship when going ahead, and it is said that such wheels are more effective than the ordinary ones.

Feathering Floats.—It is easily seen that the larger the diameter of the wheel with radial floats, the less is the obliquity at entry and exit; but independently of the objection that a larger engine is required to drive the larger wheel with the same percentage of slip, there is always the practical difficulty of arranging for a wheel of large diameter without seriously interfering with the ship's design.

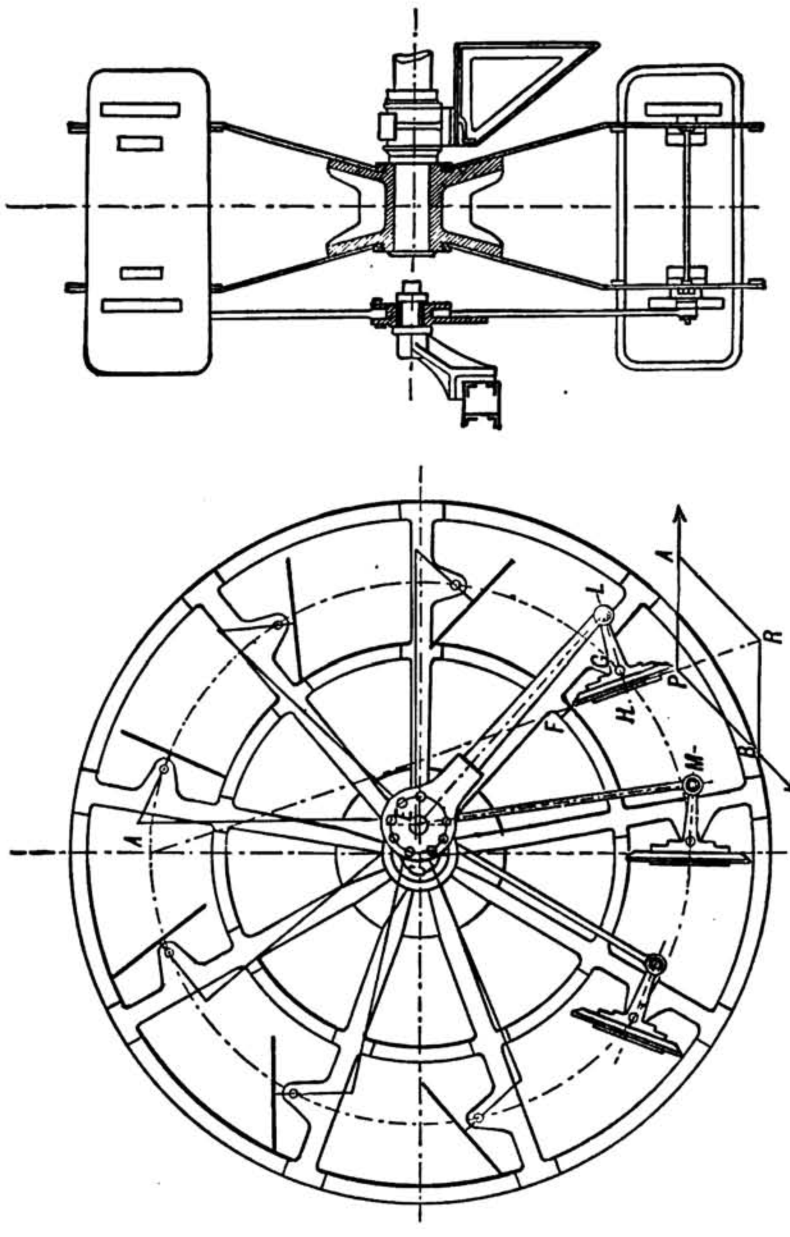

Fig. 78.—Paddle-wheel with Feathering Floats.

By means of the feathering floats, all the advantages of a large wheel are obtained without the disadvantages.

The floats of a feathering wheel, instead of being bolted to the arms, are pivoted on them; that is, they are free to move on an axis parallel to the axis of the wheel; they are retained in position by means of levers attached to them, which are operated on by an eccentric-pin or sheave by means of rods. This eccentric is so set with respect to the centre of the wheel, as to cause the float to be nearly vertical when entering and leaving the water. Fig. 78 shows an ordinary feathering wheel, from which it is seen that the floats are hung by gudgeons secured in the cross bars on their back, which fit in eyes in brackets forged with the paddle arms; one of the cross bars has a tail forged with it, which acts as the lever to turn the float. The eccentric-pin has a boss or strap running loose on it, and turned round by means of a radius rod, called the *king rod* (L E, fig. 78), attached to one of the float levers; the other radius rods are jointed both at the levers and boss. The eccentric-pin is secured in its proper position to the sponson beam, so that when the wheel moves round each float is brought in turn to the proper position for entry, &c.

To design a feathering wheel so that the floats shall enter edgeways when going at full speed, take P a point on the face of the float just entering the water, draw P A parallel to the water-line, and cut-off P A equal to the speed of the ship through the water; draw P B tangential to the circle through P, whose centre is the centre of the wheel; and cut-off P B equal to the speed of the wheel on that circle. Complete the parallelogram A P B, and the diagonal P R is the resultant of P A and P B, and is consequently the direction in which the float must move in that position to enter edgeways.

Produce R P, and draw parallel to it a line at a distance equal that of the centre of the gudgeon from the face of the float, cutting the circle of centre lines of gudgeons at G.

Draw G H at right angles to P F, and make H F and H P each equal half the breadth of the float. Make G L equal to the length of the lever required.

Now draw another float whose face is perpendicular and immediately under the centre of wheel, and the end of whose lever is M.

With centres M and L, and radius equal to G C, draw arcs of two circles intersecting at E. Then E is the centre of eccentric pin, and L E the length of the radius rods.

With E as centre and L E radius, draw a circle on which the centres of the lever ends of all the other floats lie.

It is usual, however, in practice to make the wheel equivalent to a radial wheel of double the diameter, and to construct it by taking a float vertically under the centre of shaft, and G the point on which the next float pivots. With G as centre and G H radius, draw the arc of a circle, and from the point A vertically above the centre of the wheel draw A H a tangent to this arc; then the face of the float must lie on A H, and may be drawn as before. Likewise the centre of the eccentric may be found as before.

Diameter of a Feathering Wheel is found as follows:—The amount of slip varies from 12 to 20 per cent., although when the floats are small, or the resistance great, it is as high as 25 per cent.; a well-designed wheel on a well-formed ship should not exceed 15 per cent. under ordinary circumstances.

Let v be the velocity of the ship, and S be the slip in feet per minute, and R the number of revolutions per minute at which it is intended to run the engine.

Then V the velocity of wheel at float centres $= v + S$.

V is also equal $R \times \pi \times$ diameter of wheel at centres.

Hence, $D = \frac{v + S}{\pi R}$.

Or if K is the speed of the ship in knots per hour, and S the percentage of slip, and R the revolutions per minute,

$$\text{Diameter of wheel at centres} = \frac{K(100 + S)}{3{\cdot}1 \times R}$$

Example.—To find the diameter of a wheel for a ship intended to steam 12 knots, with 30 revolutions of the engines and 20 per cent. slip.

$$\text{Diameter} = \frac{12(100 + 20)}{3{\cdot}1 \times 30} = 15{\cdot}5 \text{ feet nearly.}$$

The diameter, however, must be such as will suit the structure of the ship, so that a modification may be necessary on this account, and the revolutions altered to suit it.

The diameter will also depend on the amount of "dip" or immersion of float.

When a ship is working always in smooth water the immersion of the top edge should not exceed $\frac{1}{8}$ the breadth of the float; and for general service at sea an immersion of $\frac{1}{2}$ the breadth of the float is sufficient. If the ship is intended to carry cargo, the immersion when light need not be more than 2 or 3 inches, and should not be more than the breadth of float when at the deepest draught; indeed, the efficiency of the wheel falls off rapidly with the immersion of the wheel, and for this reason the radial wheel was so long retained for sea-going cargo boats, as it permitted of the floats being reefed—that is, brought nearer to the centre.

Area of One Float of a Feathering Paddle.—Let D be the diameter of the wheel to the float centres in feet.

Then area of one float $= \frac{\text{I.H.P.}}{D} \times C$.

C is a multiplier, varying from 0·3 to 0·35.

The number of floats $= \frac{D + 2}{2}$.

The breadth of the float $= 0{\cdot}35 \times$ the length.
The thickness of floats $= \frac{1}{12}$ the breadth.
Diameter of gudgeons $=$ thickness of float.

Paddle-wheel Frames, &c.—The strain on the wheel due to the resistance of a float is taken immediately by the pair of arms to which the float is attached, and by means of the rims is partially transmitted to the other arms. For ships working only in smooth water a much lighter wheel is sufficient than would do for those liable to the shocks of heavy seas. In any case the strength of the wheel must be sufficient to transmit the power of the engine to the water in the float-race, and as the twisting power exerted on the crank is approximately proportional to the cube of the diameter of the shaft journal, the strength of the wheel-frame must be in the same proportion. The strength of the arms of the wheel will vary directly as their thickness and as the square of their breadth. Hence, if D is the diameter of the *inner* or engine journal of the paddle-shaft, t the thickness of an arm whose breadth is b, and n the number of arms on one wheel.

$$n \times t \times b^2 \text{ varies as } D^3,$$

and

$$n \times t \times b^2 = K \times D^3,$$

or

$$t \times b^2 = \frac{K}{n} \times D^3.$$

When the shaft is of iron $K = 0{\cdot}7$ for a section near the boss, and $0{\cdot}45$ for a section near the inner rim when there are two rims. When the wheel has only one rim, so that the floats are attached to the projecting ends of the arms, the arms must be much stronger, as the whole strain may come on the pair of arms, and cause a severe bending strain close to the inner rim.

The section at the arm outside the rim may be found in a similar way, on the assumption that the distance of float centre from the rim bears a constant ratio to the diameter of the wheel (about $\frac{1}{10}$); then, if t be the thickness and b the breadth as before,

$$t \times b^2 = K \times D^3.$$

If the shaft be of iron, $K = 0{\cdot}1$.

Usually $\frac{b}{t} = 5$ for arms near the boss, and $3{\cdot}5$ to 4 for arms near the rim. When there are two rims, the arms are of uniform breadth and thickness between the rims.

When there is only one rim, $\frac{b}{t} = 6$ at the parts of the arm just at the outer edge of the rim.

The section of the inner rim is 0·8 that of the arms near to it, and $\frac{b}{t} = 5$.

The section of the outer rim is equal to that of the arm near it, and $\frac{b}{t} = 4$.

When there is only one rim its section is equal to that of the arm near the boss, and $\frac{b}{t} = 4$.

The inner rim of the wheel is stayed to the boss by round ties, whose diameter is about twice the thickness of the rim. They are bolted to the rim between the arms, and to the side of the boss opposite, so as to be diagonal with a pair of arms. This gives good support to the whole framework, and prevents racking and side-play.

Example.—To find the scantlings of a feathering wheel having inner and outer rims, the diameter of paddle-shaft journal at the engine being 10 inches, and the number of floats 8 to each wheel. The number of arms therefore is 16.

(1.) Section of arms near boss, $\left(\frac{b}{t} = 5\right)$.

$$t \times b^2 = \frac{0·7 \times 10^3}{16} = \frac{700}{16}.$$

Since $b = 5\,t$,

$$25\,t^3 = \frac{700}{16},$$

$$t = \sqrt[3]{1·75} = 1·2 \text{ inches},$$

and

$$b = 5 \times 1·2, \text{ or } 6 \text{ inches}.$$

(2.) Section of arms near rims, $\frac{b}{t} = 4$.

$$t \times b^2 = \frac{0·45 \times 10^3}{16} = \frac{450}{16}.$$

Since $b = 4\,t$,

$$16\,t^3 = \frac{450}{16},$$

$$t = \sqrt[3]{1·75}, \text{ or } 1·2 \text{ inches},$$

and

$$b = 4 \times 1·2, \text{ or } 4·8 \text{ inches}.$$

(3.) The section of inner rim $= 0{\cdot}8\ (1{\cdot}2 \times 4)$, or 3·84 square inches, and since $\frac{b}{t} = 4$, the area $= 4\,t^2$.

Hence,

$$t^2 = \frac{3{\cdot}84}{4}; \qquad \text{or } t = 0{\cdot}98 \text{ inch,}$$

$$\text{and } b = 4 \times 0{\cdot}98, \text{ or } 3{\cdot}92 \text{ inches.}$$

The outer rim has the same sectional area as the arms. The iron of arms would be then 6″ by $1\frac{3}{16}$″ at boss, and $4\frac{3}{4}$″ by $1\frac{3}{16}$″ at rims. The outer rim $4\frac{3}{4}$″ by $1\frac{3}{16}$″, and the inner rim 4″ by 1″, stayed diagonally by bars 2″ diameter.

For the wheels of steamers running only in smooth or nearly smooth water, the values of K may be reduced by 15 per cent. in each case, and if it is necessary to make the wheel as light as possible, the strength of the various parts should be calculated by finding the value of R, the resistance at the floats, and assume that the whole power of the engine may be applied to one wheel.

Let T be the maximum twisting moment in inch pounds, as found by the rules in Chapter IX., D the diameter of the wheel to float centres in inches. Then

$$R = T \div \frac{D}{2}.$$

$R \times \frac{D}{2}$ is the bending moment at the centre of the wheel; and $R \times \frac{D}{4}$ that half way between the centre and float-centres.

The bending moment at the middle of the arms is therefore

$$\frac{T}{2\,D} \times \frac{D}{4} = \frac{T}{8}.$$

And if n be number of arms, or twice the number of floats,

$$\text{Bending moment on one arm} = \frac{T}{8\,n}.$$

Then

$$t \times b^2 = \frac{T}{F \times n} \times 0{\cdot}75.$$

F may be taken at 9000 for ordinary, and 10,000 for really good iron.

The gudgeons on which the floats of a feathering wheel are hinged are not, of necessity, placed at their centre line horizontally, and it is a very general custom so to fix them that the larger part is above the axis, so that when the float is entering the water and leaving it, there is not so much strain on the radius rods. As a rule, the line of gudgeons should be $\frac{3}{8}$ of the breadth of the float from the edge nearest the centre of the wheel.

The gudgeons and pins of the feathering gear are of iron, cased with brass, and the holes in which they work should be bushed with lignum vitæ. If the ship usually works in sandy water, the pins may be of iron, and the holes bushed with white metal, which withstands the cutting action of the sand particles better than do the brass and wood.

The eccentric pin on the sponson beam should also be cased with brass, and the boss to which the feathering rods are attached should be bushed with lignum vitæ, as water is the only lubricant applied to them.

The outer bearing of the paddle-shaft should be twice the diameter of the shaft in length, very strongly made, and firmly secured to the bracket on the ship's side, as the whole of the thrust, besides the weight of the wheel, is taken on it. The force acting on it is the resultant of the thrust and weight, whose direction is diagonal, and its magnitude easily calculated. The bearing must be so formed as to take the strain, and to admit of adjustment in that direction. It is always downward, so that the caps of the bearing need not be very strong. The lubricant is to a great extent water, but an arrangement should be made for oiling, and a cavity left in the cap for a piece of tallow, or a mixture of tallow and soft soap. The shaft should have fitted to it a stuffing-box and gland, where it passes through the skin of the ship.

Screw Propellers.—The simple screw, as first fitted, consisted of a part of a true helix, cut off by two parallel planes perpendicular to the axis, and it had therefore only one blade, strictly speaking. By cutting a double helix, or a double-threaded screw in this way, two blades are obtained; and in this form, with very slight modifications, the screw propeller was used for many years. It was found, however, that by cutting away the corners, especially those on the forward or leading edges, the vibration was very much reduced, and in course of time the paring process left the screw blade very much as it is generally found now.

The number of blades was, however, increased from two to as many as six, and as there was no scientific or even practical test made of the relative advantages of six or two blades it remained for a happy accident to the six-bladed propeller of a canal boat to demonstrate that six blades were too many; since then, ample proof has been given that two blades are not sufficient in a rough sea, and that if one of three blades be broken off, the propeller is so badly balanced as to severely strain the engines, so that four blades has become the rule for the propellers of sea-going ships of the mercantile marine.

For smooth water the two-bladed propeller is the most efficient, but its efficiency is rapidly impaired so soon as the ship begins to pitch. The efficiency of a screw-propeller depends on so many things, some of which are external, that no rules can be laid down